

Enhanced coastal trapping of sediment explains offshore water clarification in the Anthropocene

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Global river sediment flux, a critical component of Earth's material cycles, is undergoing a dramatic reshaping in the Anthropocene. Recent global-scale satellite observations have revealed a developing conundrum: while nearshore waters at many major river deltas are becoming more turbid, vast continental shelf waters are simultaneously experiencing a widespread 'clarification' phenomenon. These seemingly contradictory findings challenge our traditional understanding of global source-to-sink systems. Here, we propose a "sediment spatial redistribution" hypothesis to unify these observations. This perspective represents a paradigm shift, moving the debate from a linear question of whether global sediment flux is simply increasing or decreasing to a more complex, spatial question of how it is being reorganized at the land-ocean interface. We argue that regardless of the net change in total sediment load reaching the coast, a suite of Anthropocene drivers has enhanced the efficiency of nearshore sediment trapping. Sediment is preferentially captured in zones like estuaries and deltas, while transport to the outer continental shelf is diminished. This new perspective not only provides an integrated framework for understanding coastal geomorphic evolution and ecosystem responses but also points to critical directions for future research on the global sediment cycle.

A DEVELOPING CONUNDRUM IN THE GLOBAL SEDIMENT CYCLE

Rivers, the arteries connecting land and sea, transport sediment that builds deltas and nourishes ecosystems, influencing global biogeochemical cycle.¹ For decades, the consensus has been that the proliferation of dams is trapping vast quantities of sediment, leading to a global state of "coastal starvation" and accelerating the vulnerability of deltas.²

However, this long-standing paradigm is now being challenged by new, large-scale evidence from satellite remote sensing, creating a complex and highly debatable picture. One recent 35-year analysis suggested that despite dam construction, climate-driven erosion has led to a net increase in the global land-to-ocean sediment flux.³ This finding is mirrored by observations that over 59% of major river deltas experienced a sustained increase in nearshore suspended sediment concentration between 2000 and 2020.⁴ In stark contrast, another study found that during the same period, global continental coastal waters underwent widespread "clarification," with a significant decrease in suspended particulate matter.⁵

This presents a key conundrum: why are many river mouths becoming more turbid while the broader oceans appear to be getting clearer? The issue is compounded by the considerable uncertainty and controversial nature of global datasets, as different methodologies can yield conflicting results.⁶ A cohesive theory must explain these seemingly contradictory spatial patterns—the co-occurrence of nearshore turbidification and offshore clarification—without necessarily depending on a definitive trend in the total global sediment budget.

THE SPATIAL REDISTRIBUTION HYPOTHESIS

We propose that "enhanced nearshore sediment trapping" is the key to explaining these observations. The core of this hypothesis is that Anthropocene pressures have fundamentally altered transport pathways and depositional patterns at the land-ocean interface, leading to more efficient trapping of sediment in nearshore zones, thereby reducing the flux to the outer continental shelf.

This process is driven by three primary, interacting mechanisms:

The effect of sea-level rise. A rising sea level elevates the base level for

river discharge, increasing the "accommodation space" for sediment in estuaries. Crucially, it can also enhance the strength of flood tides, which act as a powerful mechanism for trapping sediment within estuarine systems. As a result, sediment is more likely to settle and become trapped near the delta front. Furthermore, exacerbated Anthropocene subsidence in many of the world's deltas mechanistically enhances this effect, providing more accommodation space for suspended sediments during floods and leading to their redistribution and trapping across the deltaic plain.⁷

Intensified human re-engineering of the coastline. Beyond dams, widespread coastal engineering—such as land reclamation and port construction—has fundamentally altered coastal geomorphology. These structures act as physical barriers, creating sheltered areas that promote deposition. Moreover, activities like channel dredging and sand mining create new local accommodation space, further altering sediment dynamics.⁸ The cumulative global effect of this "coastal hardening" and re-engineering is a first-order driver of nearshore sediment trapping.

Changes in coastal dynamics. Climate change is reshaping regional wave climates and ocean currents. In many regions, this may lead to enhanced onshore transport or weakened alongshore currents, creating a "dynamic barrier" that "confines" sediment to the coastal zone. Although a definitive global trend remains an area of active research, regional shifts are evident.

These large-scale drivers may be amplified by changes in sediment characteristics. A potential global shift towards finer sediment loads, driven by land-use change, would enhance flocculation upon entering saline estuarine waters. While individual fine particles are easily transported, flocculation causes them to aggregate into larger, heavier flocs that settle rapidly, accelerating nearshore deposition.

Under this hypothesis, the seemingly contradictory observations depict different facets of a single, continuous process (Figure 1): sediment is increasingly being reconcentrated from offshore to nearshore environments.

FUTURE OUTLOOK AND IMPLICATIONS

This hypothesis offers important insights for the future of Anthropocene coasts:

Re-evaluating coastal resilience. The concentration of sediment in the nearshore could be a positive sign for some deltas and wetlands, potentially enhancing their capacity for vertical accretion to counteract sea-level rise and subsidence.^{9,10} However, it may also exacerbate risks of navigation channel siltation and estuarine flooding.

Potential impacts on marine ecosystems. Clarification of offshore waters increases sunlight penetration, which could alter phytoplankton communities and primary productivity. Simultaneously, the altered partitioning of sediment-associated nutrients and pollutants could create a higher risk of nearshore eutrophication while starving offshore ecosystems.

A call for future research. Future work must integrate multi-source satellite data to create a seamless monitoring system from rivers to the outer shelf. New source-to-sink numerical models are needed to couple terrestrial erosion, fluvial transport, and complex ocean dynamics. Finally, a critical next step is to move beyond the global mean to clarify the specific patterns and driving mechanisms of this spatial redistribution in different regional settings, from tectonically active margins to heavily engineered coastlines.

In summary, the global sediment story in the Anthropocene is not one of simple increase or decrease, but of a complex spatial reorganization. Understanding this process is a core scientific challenge for managing the future of the world's coastlines.

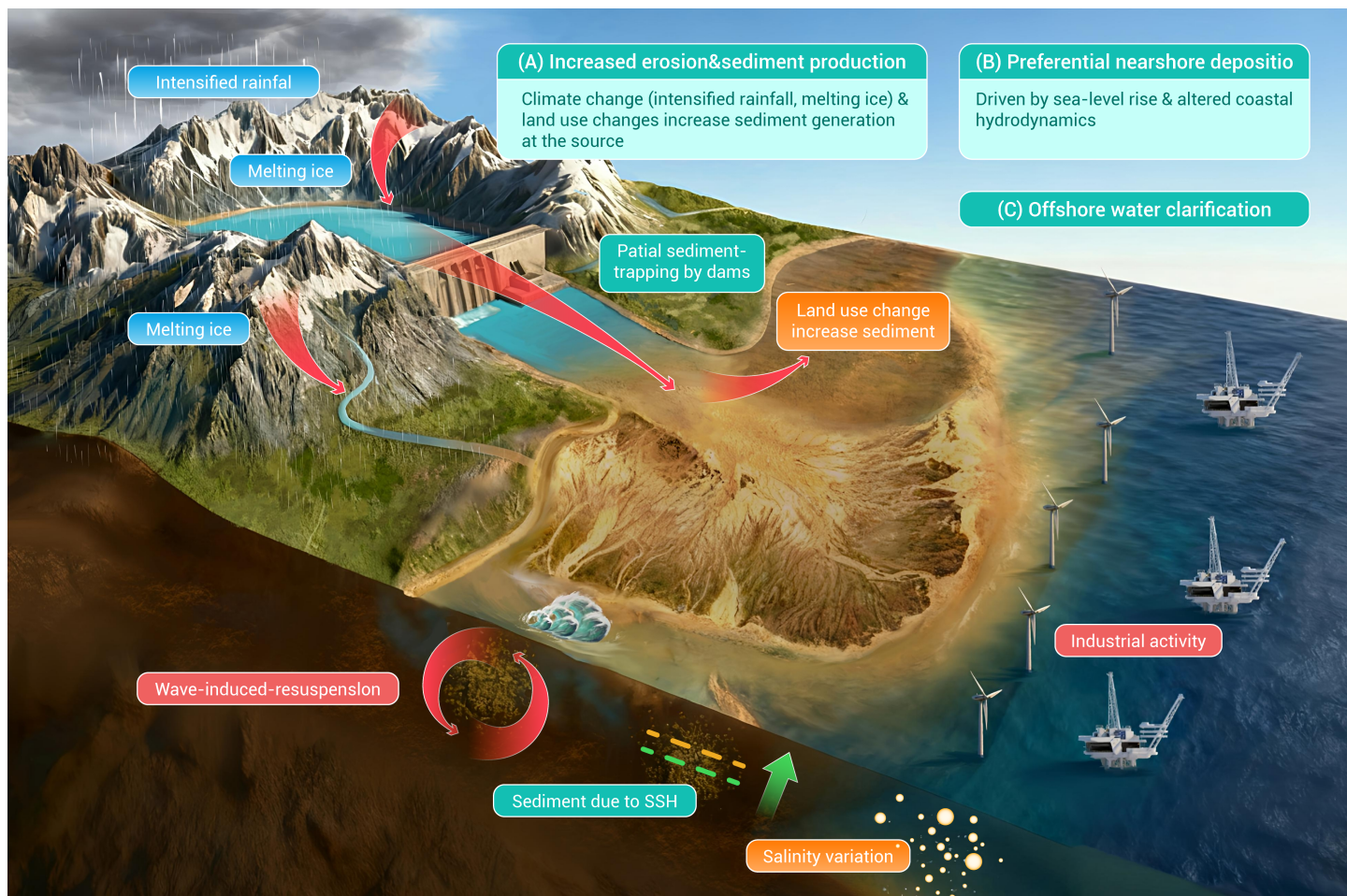


Figure 1. A conceptual model for the spatial redistribution of coastal sediment in the Anthropocene This diagram illustrates the core hypothesis. (A) Climate and land-use changes alter sediment generation at the source. While dams trap a significant portion, the net change in sediment flux to the coast remains a subject of active debate. (B) Regardless of the net flux trend, sediment is now more efficiently trapped in nearshore zones like deltas and estuaries, driven by sea-level rise, coastal engineering, and altered hydrodynamics. This leads to increased nearshore turbidity. (C) Consequently, sediment supply to the wider continental shelf is reduced, causing offshore water clarification. The overall pattern suggests a large-scale spatial reorganization that concentrates sediment near the coastline.

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AUTHOR CONTRIBUTIONS

P.C. conceived the study and prepared the original manuscript. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The author declares no competing interests.